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Comparison of gait during treadmill exercise while supine in lower body negative pressure (LBNP), supine with bungee resistance and upright in normal gravity.

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INTRODUCTION

The purpose of this study is to compare footward forces, gait kinematics, and muscle activation patterns (EMG) generated during supine treadmill exercise against LBNP with the same parameters during supine bungee resistance exercise and upright treadmill exercise. We hypothesize that the three conditions will be similar. These results will help validate treadmill exercise during LBNP as a viable technique to simulate gravity during space flight.

We are evaluating LBNP as a means to load the musculoskeletal and cardiovascular systems without gravity. Such loading should help prevent physiologic deconditioning during space flight. The best ground-based simulation of LBNP treadmill exercise in microgravity is supine LBNP treadmill exercise on Earth because the supine footward force vector is neither directed nor supplemented by Earth's gravity (Cavanagh *et al.*, 1992; Hargens *et al.*, 1991 and 1992).

Previous results from HR-95 ("Dynamics of footward force and leg intramuscular pressure during exercise against supine LBNP and upright standing in normal gravity") indicate that supine plantar-/dorsiflexion exercise in LBNP at 100 mm Hg produces similar ground reaction forces, musculoskeletal stress, and VO_2 to those during upright exercise against Earth's gravity (Murthy *et al.*, 1994). However, elevations of leg volume and heart rate indicate that cardiovascular stress during 100 mm Hg LBNP exercise exceeds that during 1g exercise. Therefore, the need arose to reduce the cardiovascular stress of LBNP, while maintaining LBNP-induced reaction forces.

To this end, we determined that mild plantar-/dorsiflexion exercise during LBNP significantly improves tolerance to LBNP via musculovenous pumping and sympathoexcitation (Watenpaugh *et al.*, 1994b); more intense exercise such as walking and running may further improve LBNP tolerance. In addition, two methodological advances have permited us to simulate upright 1g exercise better with supine LBNP exercise. First, a newly-designed waist seal allows decreased levels of LBNP (50-60 mm Hg) to produce a footward force equaling one body weight

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(Watenpaugh *et al.*, 1994a). These levels of LBNP more closely approximate cardiovascular effects of upright posture (Wolthuis *et al.*, 1974) than 100 mm Hg LBNP. The surface area spanned by the most recent waist seal (between subject and chamber structure) is twice the subject's waist cross-sectional area. Second, we developed anti-gravity ("anti-LBNP") shorts to prevent excessive LBNP-induced pooling of blood and extravascular fluid in the relatively compliant lower abdomen. These shorts consist of lightweight, inelastic material which holds an air bladder in place over the lower abdomen. This air bladder is connected to air outside the LBNP chamber via a tube through the waist seal. Therefore, the bladder automatically inflates to compress the lower abdomen in direct proportion to the magnitude of LBNP.

With data from HR-118 ("Exercise within an LBNP chamber to load cardiovascular and musculoskeletal systems in microgravity", a study performed at the University of Texas Medical Branch Clinical Research Center, Galveston, Texas), we performed a preliminary test of whether the "anti-LBNP" shorts and widened waist seal would make supine LBNP exercise more "Earth-like". Eight healthy male volunteers (age 22-42 yr; weight 58-100 kg) ran upright on a horizontal treadmill without LBNP. They also ran supine on a vertically-oriented treadmill within a LBNP chamber at

55±3 mm Hg. Heart rate was measured as each subject underwent a graded exercise protocol of 40 to 90% of upright peak oxygen uptake in each posture. Heart rate responses to supine graded treadmill exercise during LBNP (162±4 beats/minute) were similar to those during upright running exercise in 1g (161±4 beats/minute; Hargens *et al.*, 1994).

Results from the HR-139 study ("Comparison of gait and metabolism during treadmill exercise while supine in LBNP and upright in normal gravity") determined that VO_2 and HR were similar in upright and LBNP exercise. Ground reaction forces produced within LBNP were similar to forces produced during upright exercise. This is important because both the magnitude of force and the rate of force generation are thought to be necessary to maintain bone density (Rubin et al, 1985). Small kinematic differences were detected between the two exercise conditions, however, they were likely produced by the leg and back support system.

Currently, bungee resistance exercise is used during spaceflight. It has been reported anecdotally that this exercise is very uncomfortable and cannot be tolerated for long periods of time. Also, because of the discomfort, astronauts do not exercise at 1g but closer to 2/3 G (Whalen *et al.*, 1993). We are interested in determining if the bungee resistance exercise currently used during spaceflight is similar to upright or supine LBNP exercise. Therefore, the purpose of this study is to compare the differences between upright, supine LBNP and supine bungee resistance exercise.

PROTOCOL

All subjects will be thoroughly briefed and will provide informed, written consent before participating in this study. First, the exact level of LBNP necessary to generate one body weight of footward force for each subject will be determined. This involves short (< 1 minute) exposures

of subjects to resting (non-exercise) LBNP with a force plate suspended between feet and treadmill. Based on a subject's waist dimensions, waist seals are tried until one body weight of footward force is achieved at a LBNP of 50-60 mm Hg. This usually requires only one attempt.

Subjects will then be familiarized with upright 1g, supine LBNP, supine bungee resistance, and treadmill walking and running prior to the single data collection session. Comfortable speeds for level treadmill walking (3.3-5.8 km/h) and running (8.0-15.0 km/h) will be self-selected at the end of familiarization. One speed each will be selected for walking and running. For running, subjects will be encouraged to select speeds which they can sustain comfortably for moderately long periods (~10 minutes). Speeds will be chosen which do not increase heart rate above 160 beats/minute.

On the day of data collection, subjects will perform the walking/running protocol while upright on a treadmill, while supine with bungee resistance, and while supine at sufficient LBNP to generate one body weight of footward force (50-60 mm Hg LBNP), in the same experimental session. After instrumentation and collection of resting baseline data, treadmill walking will be performed at the pre-selected speeds for 3 minutes per condition. The order of exercise will be randomized for walking and running as well as for the three conditions. Speeds will be the same for bungee resistance, upright and LBNP exercise. To avoid fatigue, rest periods (no LBNP or exercise) of up to 2 minute will be allowed as necessary between the 3 minute exercise periods. This protocol requires a total of 18 minutes of treadmill exercise.

Subjects will be instrumented with ECG electrodes and an arm pressure cuff to monitor heart rate and arterial blood pressure, respectively, for safety purposes. Blood pressure by auscultation will be taken at least once at the end of each 3 minute gait period and may also be measured at other times for safety reasons. We will measure and compare supine LBNP- and upright gravity-generated reaction forces to ± 10 N with commercially-available instrumented shoe insoles using a sampling rate of 500 Hz (EQ, Inc.). EMG data will be collected at a sampling rate of 500 Hz. Surface electrodes will be placed on the quadriceps, hamstring, gastrocnemius, and anterior tibialis muscles. This data will be collected to determine the patterns of muscle activation during the different exercise conditions.

Kinematic data collected in a previous study (HR-139) have been collected and analyzed successfully within the LBNP chamber. Therefore, kinematic data for statistical comparisons will be collected during the 2nd minute of each 3 minute condition. For kinematic analyses, subjects will be videotaped using a Panasonic PV-810 camcorder at a shutter speed of 1/500 second and a frame rate of 60 Hz. To allow computerized reduction of videotape data, subjects will wear black leotards with reflective tape markers over key anatomical landmarks (5th metatarsal, heel, ankle, knee, hip, and torso).

Video data will be digitized using a Peak Performance Technologies system. Kinematic variables will include stride length, stride time, step frequency, step height, stance and swing time, as

well as amount of hip, knee and ankle flexion during the stride. Supine LBNP exercise data and upright 1g data will be compared with paired t-tests.

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